

AD-A088 281

MATERIALS RESEARCH LABS ASCOT VALE (AUSTRALIA)
A 10 MEGANEWTON (1000 TONF) FORCE STANDARD, (U)
MAR 80 E R HARRISON, F J BROWN

F/6 20/11

UNCLASSIFIED

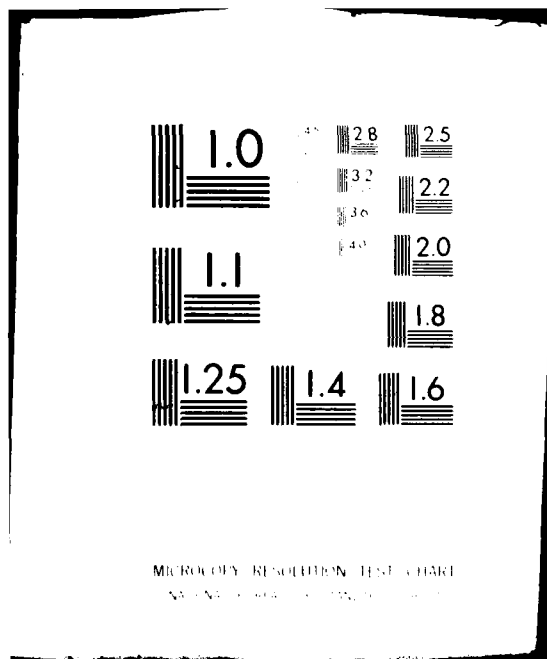
MRL-R-768

NL

| OF |
AC
B0000000



11				END DATE FILMED 9-80 DTIC
----	--	--	--	---------------------------------------



MRL-R-768

AR-002-418



DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
MATERIALS RESEARCH LABORATORIES

MELBOURNE, VICTORIA

REPORT

MRL-R-768

A 10 MEGANEWTON (1000 TONF) FORCE STANDARD

E. Raymond Harrison and Frederick J. Brown

Approved for Public Release



© COMMONWEALTH OF AUSTRALIA 1980

MARCH, 1980

AD A088281

DDC FILE COPY

80 8 27 032

DEPARTMENT OF DEFENCE
MATERIALS RESEARCH LABORATORIES

REPORT

14

MRL-R-768

6
A 10 MEGANEWTON (1000 TONF) FORCE STANDARD

10
E. Raymond Harrison and Frederick J. Brown

11/12/80
10, 18

ABSTRACT

Calibration of a force-testing machine allows it to be used as a 10-MN force standard for the testing of elastic-force calibrating devices to an accuracy of 0.2 per cent, this limitation being caused by friction of the machine's ram.

Approved for Public Release

© COMMONWEALTH OF AUSTRALIA 1980

POSTAL ADDRESS: Chief Superintendent, Materials Research Laboratories
P.O. Box 50, Ascot Vale, Victoria 3032, Australia

* 409014

JB

DOCUMENT CONTROL DATA SHEET

Security classification of this page:

UNCLASSIFIED

- | | |
|--------------------------------------|--|
| 1. DOCUMENT NUMBERS: | 2. SECURITY CLASSIFICATION: |
| a. AR Number: AR-002-418 | a. Complete document: UNCLASSIFIED |
| b. Series & Number: REPORT MRL-R-768 | b. Title in isolation: UNCLASSIFIED |
| c. Report Number: MRL-R-768 ✓ | c. Abstract in isolation: UNCLASSIFIED |

3. TITLE:

A 10 MEGANEWTON (1000 TONF) FORCE STANDARD

4. PERSONAL AUTHOR(S):

HARRISON, E. Raymond and
BROWN, Frederick J.

5. DOCUMENT DATE:

MARCH, 1980

6. TYPE OF REPORT & PERIOD COVERED:

7. CORPORATE AUTHOR(S):

Materials Research Laboratories

8. REFERENCE NUMBERS:

- a. Task: 97/017 (A17)
b. Sponsoring Agency: DST

9. COST CODE:

451840

10. IMPRINT (Publishing establishment)

Materials Research Laboratories, ✓
P.O. Box 50, Ascot Vale, Vic.3032
MARCH, 1980

11. COMPUTER PROGRAMME(S):

(Title(s) and language(s)):

12. RELEASE LIMITATIONS (of the document):

Approved for Public Release

12-0. OVERSEAS:

N.O. ☐ P.R. ☒ 1 A ☐ B ☐ C ☐ D ☐ E ☐

13. ANNOUNCEMENT LIMITATIONS (of the information on this page):

No Limitation

14. DESCRIPTORS:

636 Force standards

15. COSATI CODES: 2011

16. ABSTRACT (if this is security classified, the announcement of this report will be similarly classified):

✓
Calibration of a force-testing machine allows it to be used as a 10-MN force standard for the testing of elastic-force calibrating devices to an accuracy of 0.2 per cent, this limitation being caused by friction of the machine's ram. ↙

12

C O N T E N T S

	<u>Page No.</u>
1. INTRODUCTION	1
2. PRINCIPLE	2
3. CALIBRATION	3
3.1 <i>Multiplication factor, A/a</i>	3
3.2 <i>Measurement of M_o</i>	3
3.3 <i>Friction</i>	4
3.4 <i>Calibration of the Testing Machine as a Force Standard</i>	4
4. ASSESSMENT OF ACCURACY	5
5. COMPARISON WITH OTHER STANDARDS	5
6. FUTURE WORK	6
7. CONCLUSION	6
8. ACKNOWLEDGEMENTS	6
9. REFERENCES	7
TABLE 1: RAM FRICTION (% LOAD) FOR VARIOUS FORCES, AXIALLY AND OFF-AXIALLY APPLIED	8
TABLE 2: VARIATION (3σ LIMIT) OF FORCE (MEAN OF THREE READINGS) FROM MEAN OF READING TAKEN WITH THE RAM RISING AND FALLING, FOR THE LOADS APPLIED AXIALLY AND OFF-AXIALLY TO THE EXTENT INDICATED	8

A 10 MEGANEWTON (1000 TONF) FORCE STANDARD

1. INTRODUCTION

The application of known forces, as for example when determining the strength and other properties of materials, is usually performed in a force-testing machine. Such machines are most conveniently calibrated by an elastic force calibrating device of one sort or another. These devices are usually calibrated in a fundamental way by reference to the force of gravity acting on bodies of known mass, i.e. by reference to known gravitational forces ('dead-weights'). To develop large forces directly in this way requires inordinately large masses and it is unusual for 'dead-weight' calibrating systems to exceed about 10-kN (1-tonf) and there are very few indeed which exceed 5000-kN (50-tonf). However forces may be multiplied either by the use of a lever system [1] or by a pressure-balance system. For large forces the latter system has been used up to 16.5 MN (1650-tonf) [2] with an accuracy of 0.01%.

In Australia the largest force standard available until now has been the 500-kN (50-tonf) [1,3] lever machine at the Defence Materials Research Laboratories (MRL). It has a 10-kN (1-tonf) gravitational-force standard and this force is multiplied by a 50:1 lever. This machine has met the Australian requirements both defence and civil, for the calibration in compression and tension of elastic force-calibrating devices. It will be superseded by a 'dead-weight' standard of similar capacity now being put into service at the National Measurement Laboratory (NML), Sydney. However, there is an increasing number of elastic force-calibrating devices with a capacity exceeding 500-kN. In order to calibrate these an Amsler 10 MN compression testing machine with force applied through a hydraulic ram, 0.5 m in diameter, has been calibrated as a compressive force standard of 0.2% accuracy. In its most precise mode of operation a 10 MN force is developed through a pressure balance system which multiplies a force developed by dead-weight by 50,000 times; thus only a small gravitational force is required.

2. PRINCIPLE

The Amsler machine in fact employs a pressure-balance system for multiplying the forces produced by a pendulum dynamometer. However, to know more precisely the applied forces involved and to give a simpler measuring system, we have used the machine system merely for applying loads and, for measurement purposes, a free-piston pressure gauge accurately calibrated at NML was connected to the pressure-measuring line. The principle of the measuring system is indicated in Figure 1. The effective area of the piston of the free-piston gauge is known from its calibration and that of the ram has been obtained from measurement of its diameter and that of the cylinder in which it operates.

For equilibrium, using the symbolism of Figure 1, we have :

$$F + M_O g = mg \cdot A/a \quad (1)$$

where F = the force applied to the elastic calibrating device
 M_O = the combined mass of the ram and the calibrating device
 g = gravitational acceleration
 m = total mass (including that of the measuring piston itself)
on the measuring piston
 a = the effective area of the measuring piston
 A = the effective area of the machine ram
 A/a = multiplication

The mass M_O could not be conveniently measured directly. It was determined by measuring the pressure in the system required to balance the ram and the calibrating device with no load applied.

Friction in the machine ram, in the normal mode of operation as a testing machine, is relatively small but by no means negligible for this application. The measured magnitude for a number of conditions of loading is given in Table 1. The effects of friction are discussed in more detail in para. 3.3. Oil from the pressurised system is fed to the annulus between the ram and its mating cylinder to lubricate the bearing. Some friction remains, the actual amount depending on how nearly axially the load is applied and the rate of travel of this ram. With a controlled slow movement of the ram and on-axis loading the results are satisfactorily reproducible. Including the effects of friction f , equation 1 becomes :

$$F(1 \pm f) + M_O g = mg A/a$$

The sign to be associated with the friction f depends on whether the ram is rising (sign +) or falling (sign -). Although the magnitude of the friction is not necessarily the same in the two directions, we have assumed it to be so on the evidence discussed in para. 3.3 below. Readings are taken on the calibrating device with the ram rising and falling; the mean result is assumed to eliminate the effects of friction and equation (1) is then appropriate.

In practice it is more convenient to use the relationship in the form:

$$F = PA - M_o g ,$$

P being the pressure acting on the ram.

3. CALIBRATION

3.1 Multiplication factor, A/a

The effective area of the free-piston gauge was determined at the National Measurement Laboratory by comparison with known pressure standards to an uncertainty of less than 0.025%. The effective area of the ram was taken as the mean of the areas of the ram and its mating cylinder. The ram was raised about 200 mm out of its cylinder which was as high as we considered advisable without making provision for complete withdrawal. Comparison with a reference end-standard combination was made with a large external micrometer. The mean measured diameter was 500.00 mm with an estimated uncertainty of 25 μ m. Measurements were made of three diameters of each of three planes. In no case did any measurements differ from the mean by more than 25 μ m. The clearance between the ram and cylinder was assessed from the distance it was possible to move the ram to and fro when a large sideways thrust was applied. The diametral movement was determined as 40 μ m and the mean effective diameter was taken to be 500.00 mm + $\frac{1}{2} \times 40 \mu$ m, or 500.02 mm, with an associated uncertainty estimated to be less than 50 μ m (0.01%), giving an area of 0.19637 m² with an uncertainty of 0.02%. We thus consider the ratio of A/a to be known to be better than 0.05%.

When pressure is developed in the hydraulic system the temperature of the oil near the pump is raised and, if the pressure is maintained for long periods, say several hours, the temperature of oil in the reservoir can exceed 100°C. In operation however, this oil does not transfer to the ram and the temperature of the measuring piston remains near that of the laboratory. The effect of temperature on the multiplication is thus negligible under laboratory conditions.

3.2 Measurement of M_o

The gravitational force $M_o g$ exerted by the ram and the instrument being calibrated is allowed for by determining the pressure in the system required to balance them when no force is being exerted on the frame of the testing machine. This balancing pressure, however, is smaller than the minimum

pressure which could be measured with the free-piston gauge and therefore the balancing pressure was measured with a 0-10 lbf/in² pressure gauge which was calibrated near the time of this measurement. An accuracy of 0.1 lbf/in² (0.5 kPa) was achieved which, even at the lowest useful force (500 kN, corresponding to a pressure of 2.5 MPa over 0.2 m²) developed in the machine, represents an uncertainty of only 0.02% and is considered to be negligible.

3.3 Friction

Frictional force may be estimated by observing the difference in reading of an elastic device with the ram slowly rising and with it slowly falling, by applying very small over- and under-pressures in the system. The accuracy which can be achieved is of course limited by the readability and reproducibility of the elastic device used. In the results which follow, at least some of the variability should be attributed to the elastic proving device. The difference of the readings of an elastic proving device taken with the ram rising and with it falling is double the frictional force, if we may assume that the magnitude of the friction is equal for the two directions of the motion.

To test this assumption, we carried out experiments to measure the force with an elastic device, first centrally placed in the testing machine and then with it deliberately placed off-centre. The repeatability of the mean reading was observed to be enhanced if the rate of rise and fall of the ram was controlled to be as constant as possible and the overshoot was kept to the minimum necessary to ensure that a reverse movement of the ram would take place. We found that, although the friction increased as the axis of the elastic device was displaced from that of the ram, the mean of the readings taken "on the rise" and "on the fall" were very nearly the same in all cases, being well within 0.2% (3 σ limit) of the mean for all loads applied within 3 mm of the axis. This constancy of the mean reading supports the assumption.

Table 1 shows how friction in the ram depends on load for axial and off-axial loading, and Table 2 shows the variation (mean of three readings) of the force applied by the ram as registered by the elastic proving device for fixed pressures on the ram. Although friction increases with load, it decreases on a percentage basis with increasing force for true axial loading. We estimate that the uncertainty in an observation (mean of three readings) of the applied force due to friction is less than 0.2%.

3.4 Calibration of the Testing Machine as a Force Standard

The most accurate way of measuring forces developed by the machine is by reference to a free-piston gauge which measures the pressure in the system. This we call the basic mode of operation. It is however somewhat more convenient to calibrate the testing machine dial in the basic mode, and then compare customers' elastic devices by use of the dial. This we call the comparative mode. Additional uncertainties arise in this mode due to the lack of perfect readability, in use, of the testing-machine dial. We have assessed that the uncertainty of comparisons made directly against the machine dial when duly corrected, is 0.3%. For many calibrations this accuracy is adequate.

4. ASSESSMENT OF ACCURACY

We have indicated the sources of uncertainty of the standard above and now recapitulate them to arrive at an overall assessment for both the basic and comparative modes of operation.

4.1 Basic Mode

The uncertainty of the force applied in the basic mode has the following components :

in multiplication factor	0.05%
in M_o	0.1 kN
in m	0.005%
due to friction (mean of three readings)	0.2%

An analysis of these shows that the first three are insignificant relative to the effect of friction in the ram, and that the total uncertainty of an observation (set of three readings) is less than 0.2%.

4.2 Comparative Mode

The machine calibration in addition has uncertainties due to imperfect readability and repeatability. Repeated measurements indicate that it may be used to calibrate elastic proving devices to an uncertainty of 0.3%. The calibration curves for the lowest (100 tonf) and highest (1000 tonf) ranges of the testing machine are given in Figure 2.

5. COMPARISON WITH OTHER STANDARDS

It is always worthwhile in standards work to compare results with those obtained by alternative means and by other workers. We were able to make comparisons through the calibration of a 500-kN (50-tonf) elastic proving ring which was also calibrated against our 500-kN force standard [3] and through the calibration of two proving devices previously calibrated at NPL, Teddington, namely a 3.5-MN (350-tonf) proving ring and a 5-MN (500-tonf) force box. The results of the calibrations carried out at both MRL and NPL agree generally to within 0.1%.

6. FUTURE WORK

A cross-over rig [4] has been designed and construction is well advanced to allow the force standard to be used for forces in tension up to 3.5 Mn (350 tonf). This will further extend the facilities for force calibration in Australia.

The success achieved, albeit on a limited scale, in the work to date, points to the feasibility of developing a force standard of high capacity using high-grade gravitational-force standards of small values with relatively large force multiplication. A pressure-balance system having friction minimised by the relative rotation of the piston and cylinder of each unit could give high accuracy, of at least 0.01%, up to forces of 10 MN or beyond. Weiler et al. [2] have used a multiplication of about 1000 to achieve an accuracy of 0.01% for forces up to 16.5 MN. There seems to be no reason why a precise multiplication of about 10^4 (or even higher) cannot be achieved, as the distortion of the piston and cylinder would be small at the modest pressures developed in the system. A 10 MN force would require a balancing pressure of about 15 MPa (2000 lbf/in²) operating on a 1-m diameter piston or of about 60 MPa (8000 lbf/in²) on a 0.5-m diameter piston. For piston and cylinder units of steel, these pressures would produce changes in the effective area of the order of 0.01% and 0.05% respectively in the two cases, with rather large associated uncertainties. Using "similar" pistons in a pressure-balance system, the change in the ratio should be considerably less than these amounts, with a rather small associated uncertainty.

7. CONCLUSION

The force standard developed at MRL and described here provides a significant extension of facilities in Australia for the calibration of elastic devices in compression to 10 MN (1000 tonf) having an uncertainty of measurement of 0.3% when used in the comparative mode and of 0.2% in the basic mode.

8. ACKNOWLEDGEMENTS

The authors wish to acknowledge that Mr. G.W. Wycherley first suggested the possibility of calibrating the 1000-tonf Amsler testing machine as a force standard. They wish to thank the Director, National Measurement Laboratory, Sydney, for making available 1.3-MN and 5-MN proving devices previously calibrated at National Physical Laboratory, Teddington, for comparison.

9. REFERENCES

1. Brown, G.L. and McMurrich, R.P. (1948). 'The Characteristics of a Single-Lever of 50 Ton Capacity for Precise Load Measurement'. DRL Report 173.
2. Weiler, W., Sawla, A. and Peters, M. (1974). Sonderdruck aus VDI-Berichte, 212, 27.
3. Brown, F.J. and Hatt, D.J. (1974). 'Calibration of the DSL 50 Ton-Force (500 kN) Single-Lever Primary Force Standard'. DRL Report 551.
4. Wycherley, G.W. and Brown, F.J. (1978). Private Communication.

T A B L E 1

RAM FRICTION (% LOAD) FOR VARIOUS FORCES, AXIALLY
AND OFF-AXIALLY APPLIED

(Figures in brackets are variations, 3σ limit. Each value
was calculated from six sets of measurements, each
consisting of three readings).

Force	Axial	3 mm off axis	6 mm off axis	12 mm off axis
MN	%	%	%	%
0.5	0.17 (0.15)	0.09 (0.20)	0.28 (0.11)	0.67 (0.24)
1	0.21 (0.05)	0.38 (0.10)	0.72 (0.21)	1.2 (0.30)
5	0.11 (0.05)	0.45 (0.19)	0.61 (0.19)	-
10	0.06 (0.05)	0.32 (0.14)	0.62 (0.09)	-

T A B L E 2

VARIATION (3σ LIMIT) OF FORCE (MEAN OF THREE READINGS)
FROM MEAN OF READING TAKEN WITH THE RAM RISING AND
FALLING, FOR THE LOADS APPLIED AXIALLY
AND OFF-AXIALLY TO THE EXTENT INDICATED

Force	Applied axially and off-axially within :		
	3 mm	6 mm	12 mm
MN	%	%	%
0.5	0.10	0.13	0.11
1	0.04	0.07	0.14
5	0.13	0.38	-
10	0.15	0.17	-

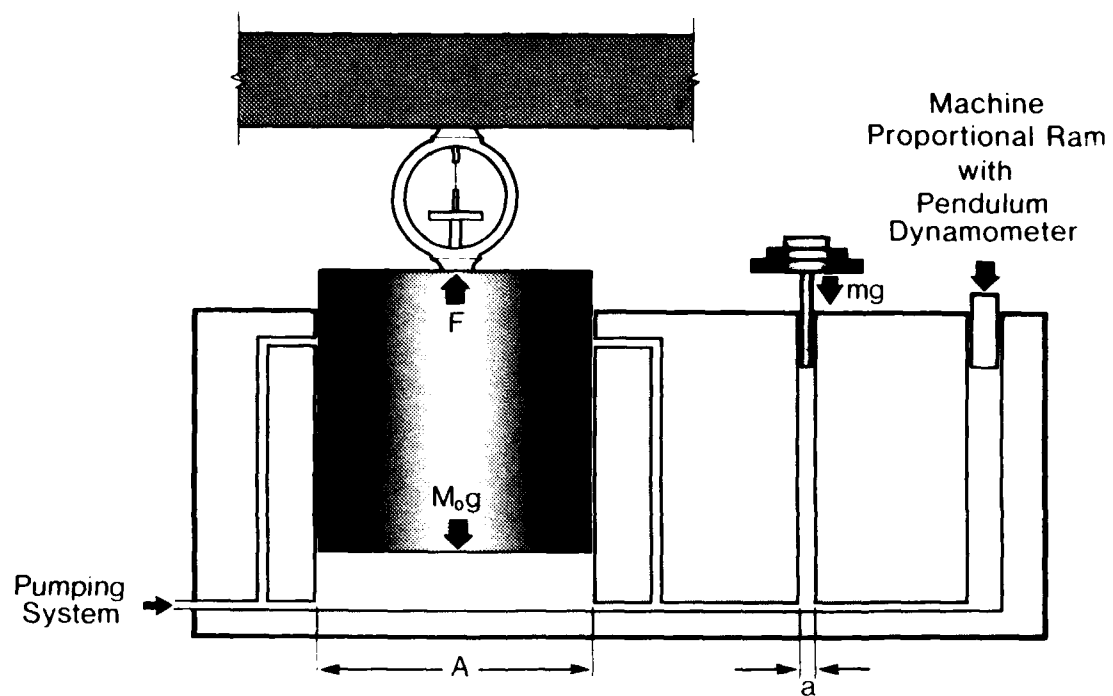


FIG. 1 - Principle of operation of 10-MN Force System.

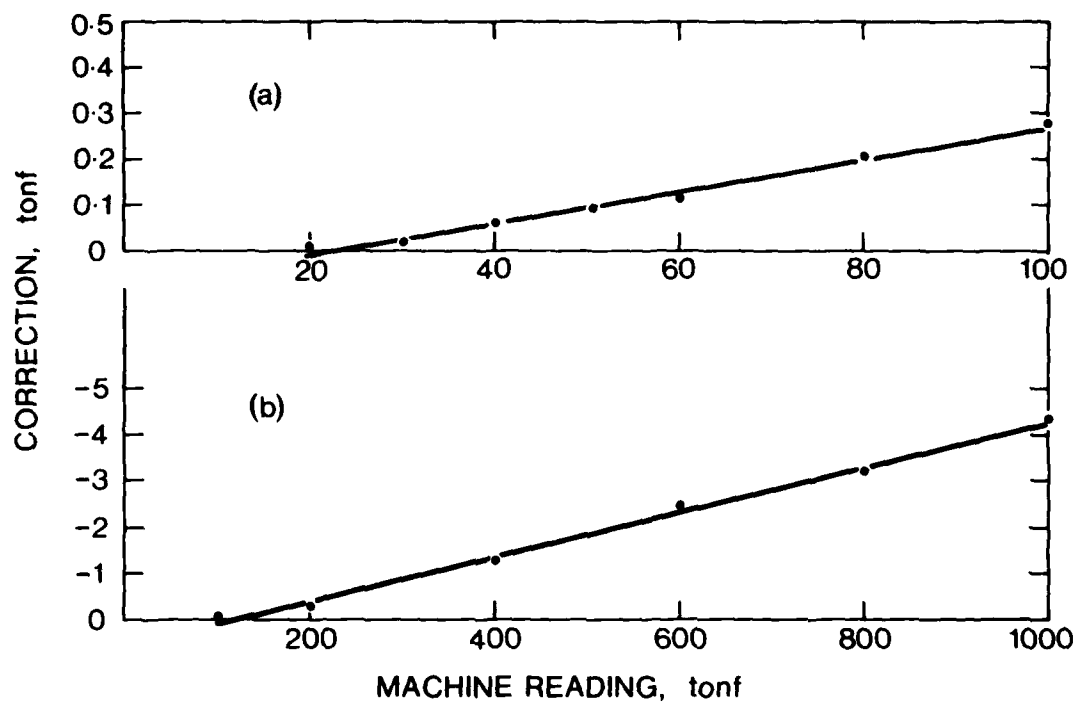


FIG. 2 - The calibration of Amsler 1000-tonf Machine,

(a) Range 100 tonf

(b) Range 1000 tonf.

(MRL-R-768)

DISTRIBUTION LIST

MATERIALS RESEARCH LABORATORIES

Chief Superintendent
Superintendent, Physics Division
Mr. E.R. Harrison
Mr. F.J. Brown
Librarian, Materials Testing Laboratories, N.S.W. Branch
(Through Officer-in-Charge)

DEPARTMENT OF DEFENCE

Chief Defence Scientist
Deputy Chief Defence Scientist
Controller, Projects and Analytical Studies
Superintendent, Science and Technology Programmes
Scientific Adviser - Army
Air Force Scientific Adviser
Navy Scientific Adviser
Chief Superintendent, Aeronautical Research Laboratories
Chief Superintendent, Weapons Systems Research Laboratory, DRC
Chief Superintendent, Electronics Research Laboratory, DRC
Chief Superintendent, Advanced Engineering Laboratory, DRC
Superintendent, Trials Resources Laboratory, DRC
Senior Librarian, Defence Research Centre
Librarian, R.A.N. Research Laboratory
Officer-in-Charge, Document Exchange Centre (16 copies)
Technical Reports Centre, Defence Central Library
Central Office, Directorate of Quality Assurance - Air Force
Deputy Director, Scientific and Technical Intelligence,
Joint Intelligence Organisation
Head, Engineering Development Establishment
Director, Naval Ordnance Inspection
Deputy Inspector of Naval Ordnance
Officer-in-Charge, Joint Tropical Trials & Research Establishment
Librarian, Bridges Library, Royal Military College

DEPARTMENT OF PRODUCTIVITY

NASA Canberra Office
Head of Staff, B.D.R.S.S. (Aust.)
Controller, Munitions Supply Division
Controller, Aircraft, Guided Weapons & Electronics Supply Division
Manager, Ordnance Factory, Bendigo
Manager, Ordnance Factory, Maribyrnong
Manager, Explosives Factory, Maribyrnong
Manager, Ammunition Factory, Footscray
Manager, Small Arms Factory, Lithgow

(MRL-R-768)

DISTRIBUTION LIST

(Continued)

OTHER FEDERAL AND STATE DEPARTMENTS AND INSTRUMENTALITIES

The Chief Librarian, Central Library, C.S.I.R.O.
Australian Atomic Energy Commission Research Establishment
The Librarian, National Measurement Laboratory, C.S.I.R.O.

MISCELLANEOUS - AUSTRALIA

The Librarian, James Cook University of North Queensland
Deputy Registrar, National Association of Testing Authorities
Assistant Technical Director, Standards Association of Australia

MISCELLANEOUS - OVERSEAS

Defence Scientific and Technical Representative, Australian High
Commission, London, England
Assistant Director/Armour and Materials, Military Vehicles and
Engineering Establishment, Chertsey, Surrey, England
Reports Centre, Directorate of Materials Aviation, Kent, England
Library - Exchange Desk, National Bureau of Standards, Washington,
U.S.A.
U.S. Army Standardization Representative, C/o DGAD (NSO),
Canberra, A.C.T.
The Director, Defence Scientific Information and Documentation
Centre, Delhi, India
Colonel B.C. Joshi, Military, Naval and Air Adviser, High
Commission of India, Red Hill, A.C.T.
Director, Defence Research Centre, Kuala Lumpur, Malaysia
Exchange Section, British Library, Lending Division, Yorkshire,
England
Periodicals Recording Section, Science Reference Library,
British Library, Holborn Branch, London, England
Library, Chemical Abstracts Service, Columbus, Ohio, U.S.A.
INSPEC: Acquisition Section, Institution of Electrical Engineers,
Hitchin, Herts, England
Overseas Reports Section, Defence Research Information Centre,
Ministry of Defence, Orpington, Kent, England
Engineering Societies Library, New York, U.S.A.